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REPORT

A statistical analyser for digital field strength data

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A STATISTICAL ANALYSER FOR DIGITAL FIELD STRENGTH DATA

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Summary

This report describes digital equipment using a microprocessor which carries out a statistical analysis of field strength data as the measurements are made. The results are obtained immediately and are printed. The analyser is intended primarily for use with a measuring receiver in a vehicle but the report also discusses the scope for other applications. The equipment obtains results which used to be obtained by manual chart analysis, thus an increase in accuracy and speed, and a saving of effort, have been achieved.

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1. Introduction

When investigating field strengths we frequently require statistical information about the way in which they vary. This information might be obtained by making a chart recording of the field strength as a function of time at a fixed location, or as a function of position if the measuring equipment is carried in a vehicle and the chart movement is linked to the road wheels. The chart recording would then be analysed to obtain the statistics required, but this is a tedious and time-consuming process. The process is also subject to human error because it depends upon visual judgements.

In view of these considerations, the equipment to be described was built. It automatically carries out a statistical analysis, as the readings are obtained, and prints out the results. The analyser accepts the readings in digital form and operates digitally throughout. It collects blocks of sample readings and obtains the following quantities for each block: median, upper and lower quartiles, upper and lower deciles, mean and standard deviation. The analyser has a capacity of 255 samples and is capable of accepting up to 20 samples per second. The event markers which mark the divisions between blocks may be signalled externally ("manually") to the analyser. Alternatively, the analyser may be set automatically to make each block either 100 or 200 samples long.

2. Theory

The median field strength for an interval of time or distance is that value above which the field strength lies for 50% of the interval and below which it lies for the remaining 50% of the interval. If a block of equally spaced samples is collected over the interval, the median is approximately the value exceeded by half the samples. Similarly, the upper and lower quartiles and the upper and lower deciles are approximately the values exceeded by 25%, 75%, 10% and 90% of the samples, respectively.

The analyser begins by storing the samples in order of size, as they are collected. Thus, when a sample is collected, all the samples which are larger than it are moved over by one space in the memory to make room in the right place for the new

sample. The data will thus be ready for analysis whenever the block ends, i.e. whenever the event marker occurs.

Suppose a completed block of samples contains n readings designated x_1 to x_n , stored in order, x_1 being the smallest. The analyser obtains the statistical quantities mentioned above, according to the following rules:

$$\text{median} = x_i$$

$$\text{where } i = \left\lceil \frac{n}{2} \right\rceil + 1 \text{ and } \left\lfloor \frac{n}{2} \right\rfloor \text{ is the integer part of } \frac{n}{2}$$

$$\text{lower quartile} = x_j$$

$$\text{where } j = \left\lceil \frac{i}{2} \right\rceil \text{ except that if } \left\lfloor \frac{i}{2} \right\rfloor = 0, j = 1$$

$$\text{upper quartile} = x_k$$

$$\text{where } k = n - j + 1$$

$$\text{lower decile} = x_p$$

$$\text{where } p = \left\lceil \frac{n}{10} \right\rceil \text{ if } R < 5, \text{ or } \left\lfloor \frac{n}{10} \right\rfloor + 1 \text{ if } R \geq 5,$$

except that if this would give $p = 0$, $p = 1$. R is the remainder from the integer division $n \div 10$.

$$\text{upper decile} = x_m$$

$$\text{where } m = n - p + 1$$

The effect of these rules is such that if no sample corresponds exactly to a particular quartile or decile the next sample further away from the median is taken. This is a further slight approximation, in addition to that involved in sampling.

The mean and standard deviation are obtained as follows:

$$\text{mean, } \bar{x} = \frac{\sum x_i}{n}$$

$$\text{standard deviation} = \sqrt{\frac{\sum x_i^2}{n} - \bar{x}^2}$$

It may easily be shown that this expression for standard deviation gives the same result as the more familiar expression

$$\text{standard deviation} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}}$$

Note: It is convenient to use the divisor n instead of $(n - 1)$ which would be slightly more accurate.

These methods of operation have been chosen so that the data may be sorted and the sums accumulated as the samples come in, rather than when the block ends. This makes it possible for all the processing required at the end of a block to be completed in the interval between two sampling instants. In this way, the memory can be used afresh to store the data for each successive block, without the need for any special measures when one block ends and the next begins.

We have chosen the median as the representative field strength for a block. This is because the mean differs according to whether the field strength is expressed in terms of electric field, power density or a logarithmic scale, whereas the median is unchanged; and also because the mean is more affected by any extreme fluctuations in the field strength. The analyser was designed with the RC1M/14* and RC1M/21² field strength measuring receivers in mind. These receivers obtain the field strength directly in decibels above $1\mu\text{Vm}^{-1}$ in digital form so that the mean and standard deviation apply to readings expressed on a decibel scale. Caution is therefore needed in their interpretation unless the field strength distribution is log-normal. The mean and standard deviation will also be useful if the analyser is used for processing data expressed on a linear scale.

* A report¹ has been written on the basic receiver; the RC1M/14 represents the current version with a modified layout.

3. Specification

The specification is written in terms of the particular application for which the analyser was built. However, it should be borne in mind that the analyser is of more general application. The analyser collects each sample in response to an external signal (which we may call a sampling trigger pulse), so it can collect samples at equal intervals of time or distance or in any way which may be required, subject to a minimum time between samples. It could analyse an analogue signal if a suitable analogue-to-digital converter was provided. In this case the internal conversion from binary coded decimal (BCD) to binary would be omitted and the analyser would accept a sample accuracy of up to eleven bits.

Our more immediate application is the analysis of field strength variations with distance, and we have chosen to collect each block of data over a section of road between 0.5 km and 2.5 km long. Suppose we require at least 100 samples in a block in order to give reasonably accurate statistics, then samples need to be collected every 5 m along the road. In practice, it was convenient to produce pulses every 0.2 m and to include a divide by 25 circuit in the analyser.

3.1 Handling of data

Size of data memory — 255 samples. If 256 sampling trigger pulses are received before an event marker occurs, alternate samples in the memory are discarded to make room for 127 more, the accumulated sums are halved, and sampling continues on alternate trigger pulses. If the block has not ended by the 510th pulse, an automatic event marker occurs, and the block is terminated and processed.

Section length — up to 2.55 km, for the above reasons.

Sampling interval — every 5 m along the road up to 1.275 km section length; every 10 m from 1.28 km to 2.55 km, for reasons given above.

Maximum rate of sampling — at least 20 samples per second.

Quantities computed — median, upper and lower quartiles, upper and lower deciles, mean and standard deviation. (In the unlikely event that the standard deviation exceeds 25.5 dB, an overflow occurs and an incorrect result is obtained). For formats of

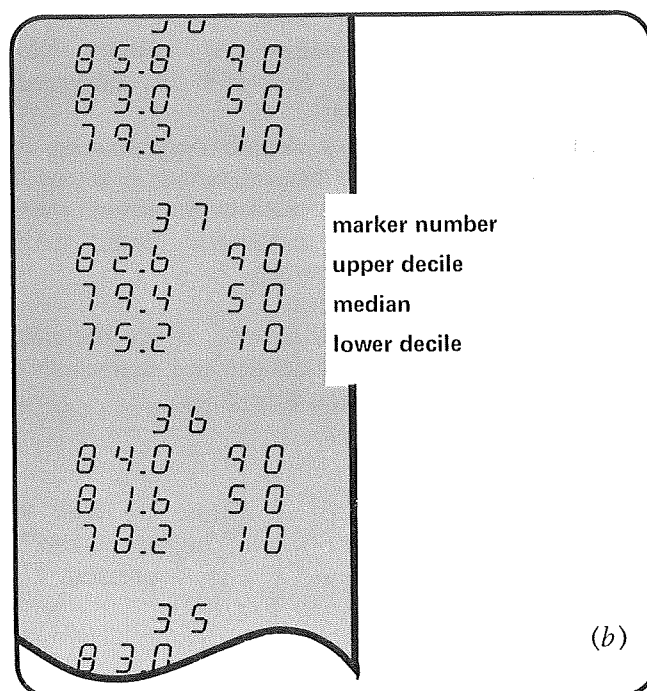
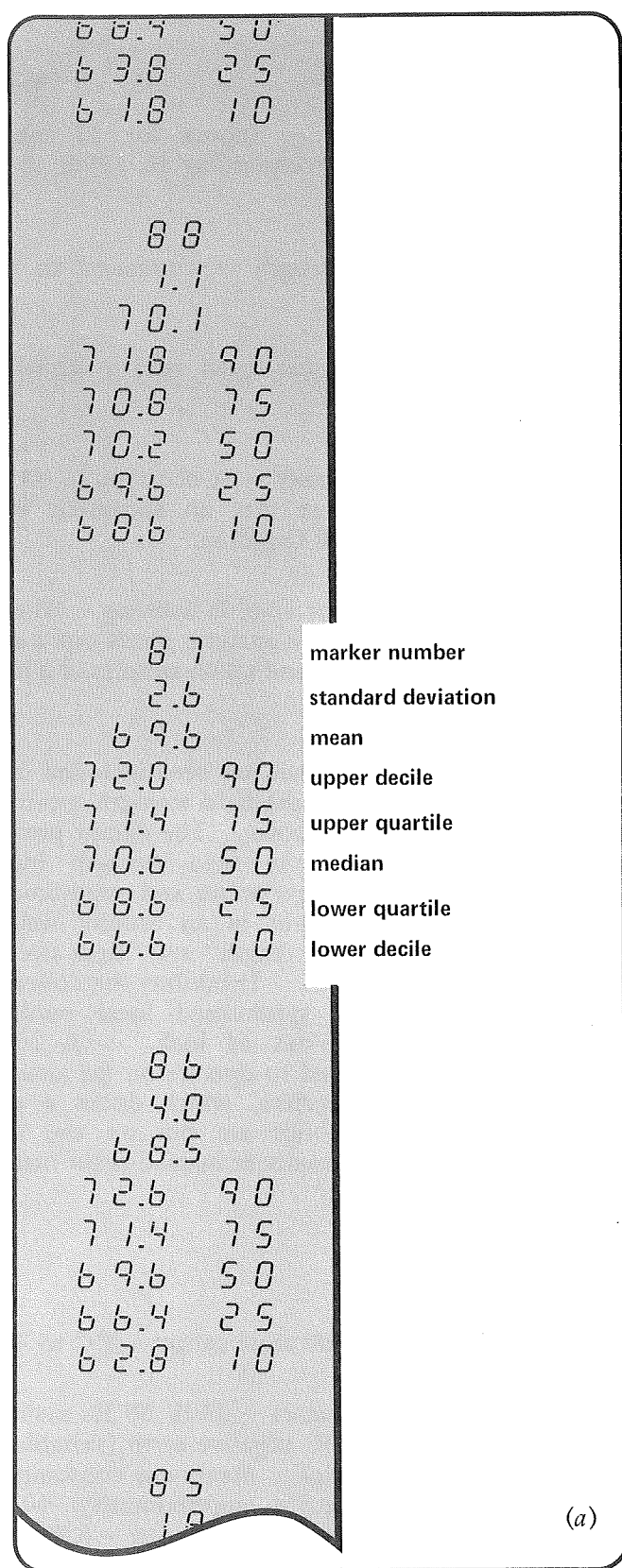


Fig. 1 - Formats of print-out

(a) Full print-out
(b) Reduced print-out

print-out see Fig. 1. If a result is outside a certain range, currently 10 to 120 dB, a + sign (too large) or a - sign (too small) is printed.

Printer — A small line printer with seven segment numerals using heat-sensitive paper. Each line is visible as soon as it has been printed.

3.2 Switches

The divisions between blocks are signalled to the analyser by event markers. The analyser numbers the event markers in sequence. The marker number counts up or down; the counting sequence is ...98, 99, 00, 01,... or the reverse. The number is printed between each set of results and the up-to-date number is shown on a liquid crystal display. The marker number is controlled by switches as described below.

Option switches — These are on a dual-in-line switch package. When "begin/end run" is pressed, the analyser reads which options have been selected.

- (1) Auto/manual
 - Off — manual event markers: triggered by event marker push-button or after 2.55 km.
 - On — automatic event markers: triggered

every 0.5 km or 1 km along the road (after 100 or 200 samples have been collected) according to option No. 2. Event markers can still be triggered by the push-button.

- (2) $\frac{1}{2}$ /1 km. This switch only has an effect when the auto/manual switch is set to auto.
Off — 0.5 km automatic event markers.
On — 1 km automatic event markers.
- (3) Full/reduced print-out.
Off — full print-out.
On — reduced print-out. Only the median, upper and lower deciles and marker number are printed. See Fig. 1

Initial marker number

Marker number count direction

} These are read when "begin/end run" is pressed.

Increment/decrement marker number — Momentary operation of this switch changes the marker number by one at any time except during printing.

Begin/end run — Pressing this switch causes the options, the initial marker number and the count direction to be set up in the analyser. In auto mode it also constitutes the first event marker of the run, thus allowing the event marker push-button to be dispensed with. In manual mode the analyser only starts collecting samples after the next operation of the event marker push-button. "Begin/end run" works at any time except during printing; thus it causes any part-completed block of samples to be lost. In short, "begin/end run" prepares the analyser for a run, in which a number of consecutive blocks of data are collected and analysed.

Event marker — a push-button on the end of a cable, used for signalling the divisions between blocks of readings. Event markers can also be triggered automatically (see options). When the first event marker of a run occurs, the analyser prints the marker number. After subsequent event markers, the analyser updates the marker number, processes the block of data which has just been collected and prints the results. It takes about 3s for a full print-out, and 1.5s for a reduced print-out. The event marker, in common with the other switches, does not operate during printing. The analyser does, however, start collecting a new block of

samples during printing.

3.3 Signal connections

Field strength — Inputs for 13 bits in BCD form, corresponding to 199.9 at full scale.

Read field strength — command to microprocessor.

Field strength has been read — signal from microprocessor.

Auto event marker — A short pulse on this output indicates that an automatic event marker has been triggered.

Trigger pulse for audible warning — When in manual mode, the analyser sends out a short pulse as the 80th and 180th samples of a block are read.

An interface circuit has been included in the analyser for use with the field strength measuring receivers mentioned above. The circuit provides synchronization for the field strength inputs. It accepts sampling trigger pulses, and communicates with the microprocessor in an orderly way by using the "read field strength" and "field strength has been read" signals. It inhibits the collection of samples if the synthesised local oscillator in the receiver is out of lock. A circuit has also been provided to operate on the analogue signal from the receiver, which drives a chart recorder, so that blips are put on the chart recording when automatic or manual event markers occur.

3.4 General

Operating temperature range — 0°C to 40°C

Power requirements — 240V 50 Hz mains or 11V to 33V DC negative earth (suitable for use in a vehicle). Maximum consumption when printing — approximately 40 W. Consumption when not printing — 6 W.

Weight — 8 kg.

Dimensions — Standard MAJAR case 530 x 300 x 200 mm.

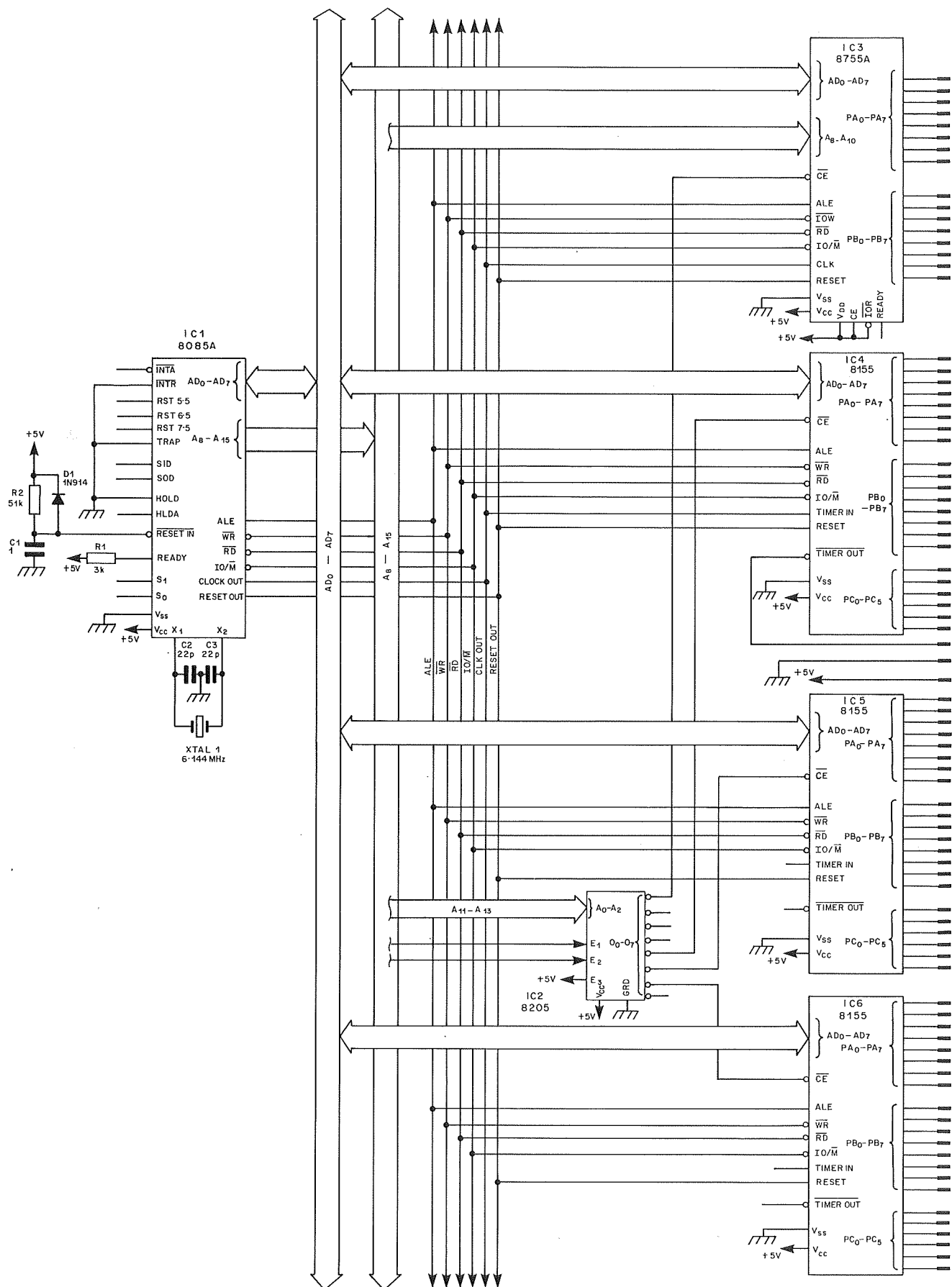


Fig. 2 - Circuit of microprocessor card

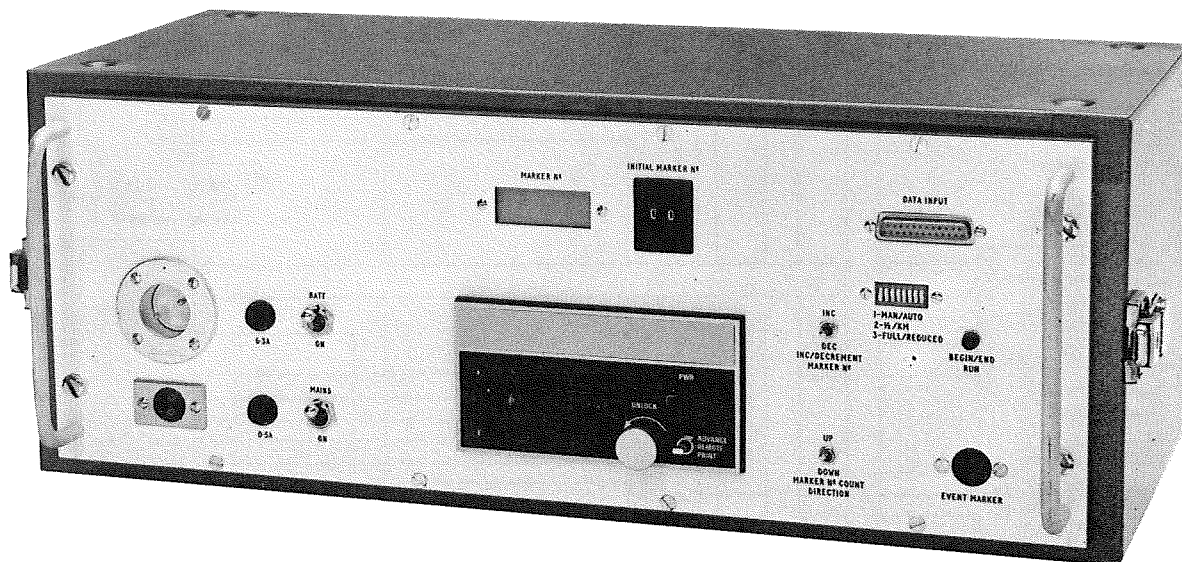


Fig. 3 - Front panel

4. Design

The sequence of operations required from the analyser is fairly complicated, which means that the analyser must operate under the control of a program of some kind. The use of a program has the advantage that the sequence of operations can be modified by reprogramming without the need for extensive rewiring. Another design consideration is that a calculator chip would not be fast enough for the accumulation of the sums.

For these reasons, the analyser has been based on a microprocessor. The microprocessor carries out all the operations except those of the interface circuit described above. When the analyser was first used it became clear that a number of improvements could be made, and the ability to change the program proved very useful.

One disadvantage of a microprocessor is that writing a program is time consuming. The program was written in assembly language*. A higher-level language was not available at the time, nor were arithmetic routines. An assembler was used to convert the program into machine code. Each instruction in the program generates one, two or three 8 bit bytes in the assembled code. The complete program occupies 1796 bytes.

* Much of the program was written by B. Tait.

It is difficult to write assembly language programs so that they may be readily interpreted by someone other than the writer. They are also very prone to errors in the detail of the logic. However, they usually have shorter execution times than programs written in a higher-level language. For the arithmetic routines, simpler programming and faster execution were achieved by working in binary rather than BCD, and including programs for conversion between BCD and binary. The program was initially run in a development kit. It was subsequently reassembled for use in the analyser.

Most of the components are mounted on three plug-in cards. The cards have double-sided 56-way connectors to accommodate the large number of interconnections required. The circuit diagram of the microprocessor card is given in Fig. 2. Only five large-scale integrated circuits, and one medium-scale, are used, and only one power supply is needed. The front-panel layout is shown in Fig. 3 where many of the features mentioned in the specification may be seen.

The power supply uses a commercial d.c. to d.c. switching mode converter. This caters for a wide range of battery voltage while maintaining a high efficiency of conversion. The converter provides a well regulated 5V output and supplies power to all the components in the analyser. For

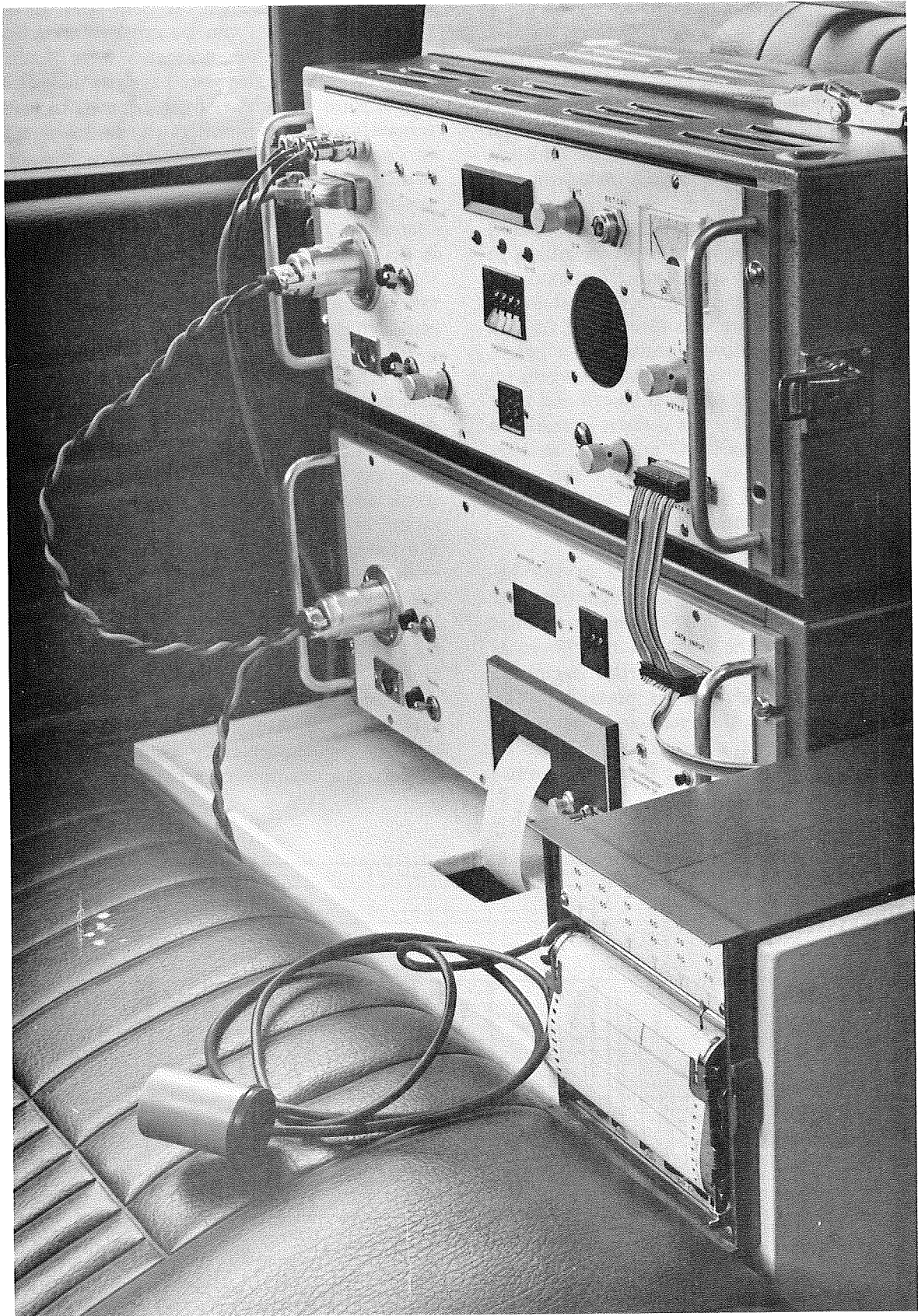


Fig. 4 - The analyser and a receiver set up in a car

mains operation, the converter is fed from a transformer and rectifier.

5. Operation

We have found that the most convenient method of operation for field strength measurements is as follows. The analyser and a receiver are set up in a vehicle, and the route along which measurements will be made is marked on a map. If the measurements are to be repeated for another transmission or with a different receiving aerial it is convenient to follow the identical route each time. For example the user could arrange a route to begin and end in the same place, or follow one radial line from a transmitter and return along another on a neighbouring bearing. By this means, the chart recordings from each trip will be of equal length and they can be compared directly. It is then possible to use automatic event markers, and, if the first event marker is in the same place, all the event markers from each trip will match up, and the printed results can be compared directly.

Thus, before the vehicle arrives at the beginning of the route, the $\frac{1}{2}$ km auto event marker option is selected and the print option, initial marker number and count direction are chosen as required. As the vehicle passes the beginning of the route, "begin/end run" is pressed. The journey is followed on the map and, where an event marker occurs at a point which can be identified on the map, this point is marked on the

map and labelled with the corresponding marker number. The positions of the remaining markers can be interpolated on the map later on and thus each set of results can be cross-referenced to the place where the measurements were made. The marker number is also noted against the corresponding blip on the chart, from time to time, and the remaining marker numbers can be filled in later on to complete the cross-references. If a mistake is made, such as taking a wrong turning, it may be possible to return to the location of the last identified marker. The number of this marker is dialled up, "begin/end run" is pressed, and the journey is resumed. The increment/decrement marker number switch is also provided to assist in recovering from mistakes.

There is a trade-off between the use of manual and automatic event markers. With manual event markers the locations of the markers need to be chosen beforehand and marked on the map. If they are suitably chosen there may be very little work to be done after the journey, in order to arrive at the final results. This does mean that the navigator is working under pressure to trigger each marker in the right place during the survey. We prefer the automatic mode because it makes life easier in the vehicle, though more work is required subsequently to produce the results.

Fig. 4 shows the analyser and a receiver in a car. They are housed in similar cases and the data sockets are conveniently connected by a ribbon cable. An example of a chart recording is shown

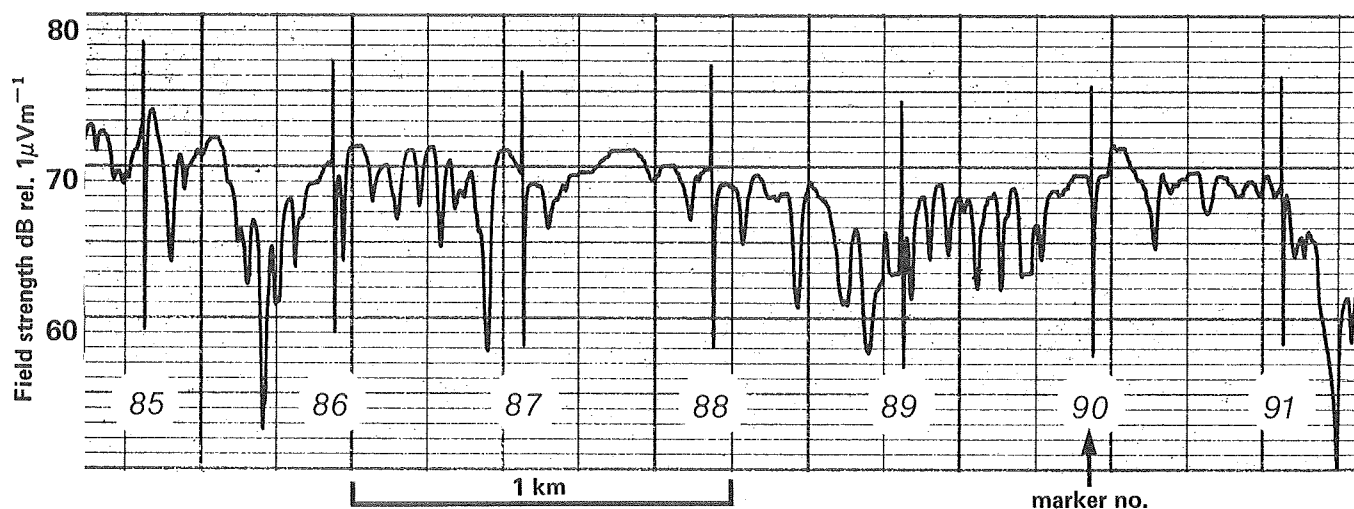


Fig. 5 - Example of chart recording (relates to Fig. 1 (a))

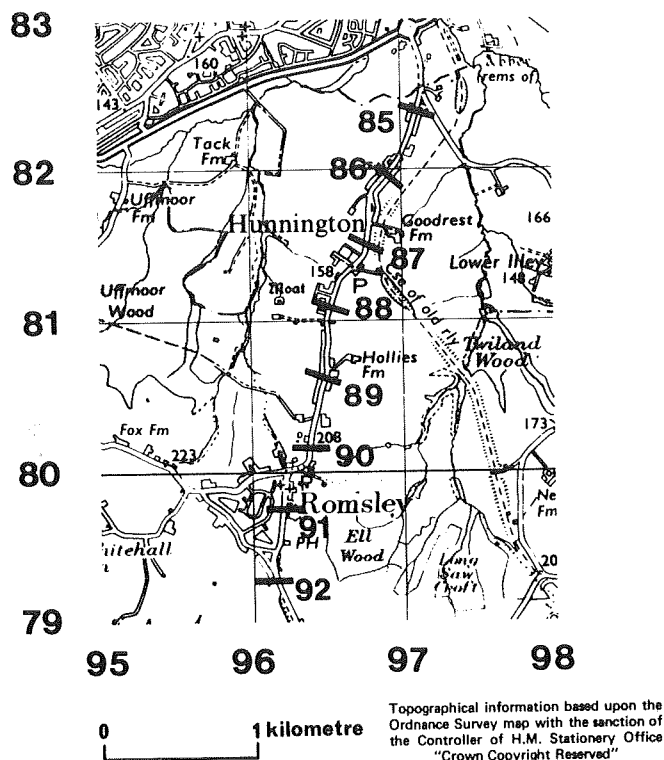


Fig. 6 - Annotated map corresponding to Figs. 1(a) and 5.

in Fig. 5. The event markers are clearly visible. This trace was obtained at the same time as the print-out of Fig. 1(a). The corresponding annotated map is shown in Fig. 6. The marker numbers have been noted on the chart and the map.

6. Conclusions

The use of the analyser represents a considerable advance over the process of manual chart analysis. The results are obtained quickly and accurately and much less effort is required. The analyser is easy to use and offers a range of facilities for controlling the handling of the data. It stores a set of samples so that it is able to obtain fractional parts of a field strength distribution. The application of the analyser is not restricted to field strength measurements: for example, it could easily be adapted to obtain data from an analogue-to-digital converter.

7. References

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